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THE ADVANCED ORBITING SYSTEMS TESTBED PROGRAM: RESULTS TO DATE

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ABSTRACT

The Consultative Committee for Space Data Systems Recommendations for Packet Telemetry and Advanced Orbiting Systems (AOS) propose standard solutions to data handling problems common to many types of space missions. The Recommendations address only space/ground and space/space data handling systems. Goddard Space Flight Center's AOS Testbed (AOST) Program was initiated to better understand the Recommendations and their impact on real-world systems, and to examine the extended domain of ground/ground data handling systems.

Central to the AOST Program are the development of an end-to-end Testbed and its use in a comprehensive testing program. Other Program activities include flight-qualifiable component development, supporting studies, and knowledge dissemination. The results and products of the Program will reduce the uncertainties associated with the development of operational space and ground systems that implement the Recommendations. The results presented in this paper include architectural issues, a draft proposed standardized test suite and flight-qualifiable components.

Key words: AOS Testbed, CCSDS, service and network management, SOSDU, testing, flight-qualifiable components.

1. INTRODUCTION

Goddard Space Flight Center's (GSFC's) Advanced Orbiting Systems (AOS) Testbed (AOST) Program provides the bridge between development and widespread use of the Consultative Committee for Space Data Systems (CCSDS) Recommendations for Packet Telemetry and AOS (Refs. 1-2). The Recommendations, which will be used by future NASA missions, offer the promise of significantly reducing mission life-cycle costs by standardizing data handling interfaces in both space and ground systems. Standardization allows the reuse of hardware and software, and facilitates agency interoperability in national and international programs.

The AOST Program is using a multi-faceted approach that will reduce the remaining costs and risks associated with the use of the Recommendations by

NASA. This paper presents results and products of AOST Program activities to date (November 1992). The results and products have significant implications with respect to the development of systems built in accordance with the CCSDS Packet Telemetry and AOS Recommendations.

2. AOST PROGRAM OVERVIEW

This paper is a companion paper to (Ref. 3), which provides a detailed description of the AOST Program. A high-level overview of the Program is given in this section to provide a context for the discussion of activities and results to date. Readers interested in a more comprehensive description of the AOST Program, its goals, objectives, and work activities are referred to (Ref. 3).

The AOST Program comprises five work activities: developing and using the AOST, developing flight-qualifiable components, conducting a test program, performing supporting studies, and disseminating the knowledge gained and products developed through Program activities. Detailed descriptions of these activities are presented in (Refs. 3-4).

The services defined in the Recommendations are being implemented in the AOST to demonstrate that there is at least one technically feasible, economically acceptable solution for providing each service and to perform real world validation of ground implementability in technology, operability, and manageability. *It is not intended that the AOST select a particular design solution for CCSDS services.* The AOST contains multiple implementations of many of the CCSDS services, providing a platform for testing alternative design solutions through which critical information can be provided to program management, industry, and the CCSDS.

The AOST is being developed as a series of four Capabilities, each distinguished by the CCSDS services and functions provided. The AOST comprises all of the subsystems of an end-to-end CCSDS-based data handling system, and includes both space and ground elements. Capability One (C-1) space elements include an instrument simulator and a frame generator that creates Virtual Channel Data Units (VCDUs). Ground systems include a front end, multiple service processors, and, in

Capability Two (C-2), a communications address processor and service and network management elements. The ground system elements process the VCDUs generated by the space elements to provide the CCSDS service(s) designated by the end user via the service and network management elements.

3. ACTIVITIES TO DATE

The AOST Program has produced a number of documents in support of Program activities. These documents establish Program goals and approach, allocate functions to space and ground system elements, define Testbed interfaces, and represent initial development efforts in service and network management. The AOST Program Plan (Ref. 4) defines the goals and objectives of the Program and the technical approach to achieving those goals and objectives. The Program Plan also summarizes the allocation of functions to the Testbed space and ground system elements. The Interface Definition Documents (Refs. 5-9) and the Space Operations Service Data Unit (SOSDU) Format Definition Document (Ref. 10) define the internal and external data and protocol interfaces of the Testbed. Draft specifications for service management interfaces with ground system elements (Refs. 11-12) define the management interfaces that support efficient use of resources and systems.

The C-1 AOST delivered in March 1992 provides three CCSDS AOS services: Virtual Channel Access (VCA) service, VCDU service, and Path Packet service. The AOST team established and documented ground rules governing the implementation of these services in C-1 (Ref. 13).

Functional testing of the C-1 AOST is still in progress. Research testing will be initiated upon completion of functional testing. The Master Test Plan (Ref. 14) and C-1 Test Plan (Ref. 15) define the general test program and the C-1 test program, respectively. The C-1 test program has produced a number of findings, most of which have been specific in nature and related to software debugging rather than issues related to the CCSDS Recommendations. A few significant issues have been identified and are addressed in this paper. The test program is also supporting the development of a suite of standard conformance and compatibility tests for use by CCSDS system developers.

The European Space Agency (ESA), Canadian Space Agency, National Space Development Agency of Japan, and the Deep Space Network Prototyping Laboratory at Jet Propulsion Laboratory (JPL) have expressed interest in cooperative testing using the AOST. A draft test plan for joint testing using the

AOST and ESA's Space Data Network Testbed is currently under review by NASA and ESA (Ref. 16).

The development of flight-qualifiable components is well ahead of schedule. A preliminary specification has been issued for a Reed-Solomon (R-S) encoder chip (Ref. 17).

Several members of the AOST Program team are supporting the CCSDS and the Space Operations Services Infrastructure (SOSI) working group. The SOSI group is a joint GSFC/JPL team that is developing service and operations concepts and identifying cross-support points, protocols, and formats common to all NASA implementations of CCSDS services (Ref. 18).

A library of AOST Program and related documents has been established as a central repository of knowledge gained and products of the AOST Program. The first "Workshop for CCSDS Implementors" was held at GSFC on November 4-5, 1992, under the sponsorship of the AOST Program. The Workshop was attended by more than 300 people representing 44 U.S. companies, the Department of Defense, 2 universities, 4 NASA centers, and NASA Headquarters.

4. RESULTS

The results of the AOST Program to date apply to three different aspects of the Program: the AOST architecture, a draft proposed standardized test suite, and flight-qualifiable component development. Findings related to the AOST architecture were identified through the development process and C-1 test program. The proposed test suite is a product of the C-1 test program. One of the flight-qualifiable components has been baselined by two GSFC missions.

4.1 Architecture

The architecture-related findings discussed in this section have resulted from the C-1 AOST development process and subsequent C-1 test program. Of primary importance are the ground rules identified to govern the AOST development process, the SOSDU format, service and network management, AOST scheduling and configuration, and latencies induced by the selected implementation of the AOST architecture.

4.1.1 Ground Rules

Ground rules (Ref. 13) for data processing were identified early in the C-1 development process as part of the developers' set of requirements. The domain of the CCSDS Recommendations ends at the

space/ground interface; the Recommendations do not address the requirements for implementing a ground system. The ground rules are needed to standardize ground/ground interfaces and ground processing among multiple implementations of the CCSDS services. The ground rules cover parameterization of data, processing requirements related to data characteristics, and processing requirements related to error conditions. While the AOST ground rules have not yet been proposed for adoption by the CCSDS community, it will be necessary to adopt some common set of ground rules, or for similar ground rules to be incorporated into a CCSDS Recommendation.

4.1.2 SOSDUs

The SOSDU data structure (Ref. 10) "extends" the CCSDS Recommendations to ground system interfaces. The SOSDU allows for the process-oriented decommutation of CCSDS data structures while preserving the service types and providing a mechanism for the incorporation of metadata related to the processing of the CCSDS data. The SOSDU header currently contains a generalized label and a SOSDU label common to all SOSDUs, a set of service parameters specific to each of the CCSDS services, and optional agency- and/or network-unique fields. The SOSDU is in an early stage of development and is expected to change significantly within the next several months. The SOSI group is identifying SOSDU requirements based on a global perspective of cross-support points, protocols, and formats.

4.1.3 Service & Network Management

AOST Service Management will explore ways to improve the efficiency of network operations and resource utilization in networks providing CCSDS-based services. Currently, ground systems handling space data are geared to scheduled, circuit-switched communication services. The ability to trace end-to-end data flows and determine system performance is largely dependent on verbal reporting mechanisms and operator intervention. Problems are usually detected and reported first by end users. The users must be familiar with the operation of the ground infrastructure to make use of the system's functionality.

The Service Management system being developed for the AOST (Refs. 11-12) allows users of a CCSDS service-providing network to interact with that network in terms of services rather than equipment configurations, and manages the equipment configurations of multiple facilities and subnets. AOST Service Management distributes service configuration information, generates periodic reports about the

quality of services, and monitors network elements for fault isolation. The AOST Service Management function will provide greater fault detection, isolation, and recovery capability for CCSDS data services.

AOST Service Management uses a distributed hierarchical architecture comprising a central Network Management Integrator and Coordinator (NMIC), multiple Complex Managers, and their associated managed systems. The AOST Service Management hierarchy is illustrated in Figure 1.

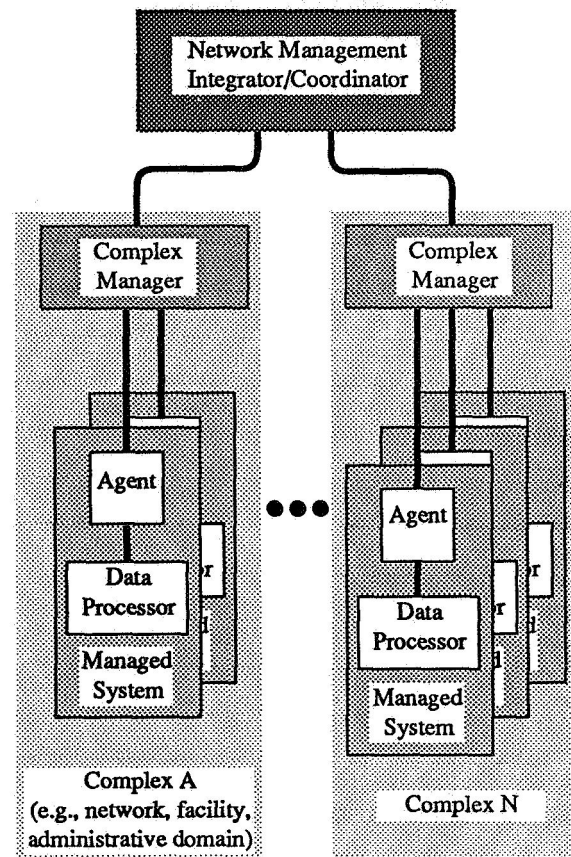


Figure 1. Service Management Hierarchy

The NMIC interfaces with the user community and coordinates the services provided by multiple complexes. Each Complex Manager manages the operation of a single complex, such as a subnetwork, facility, or administrative domain. Complex Managers manage local equipment as well as services. The systems comprising a complex must each support an agent that translates the local representation of information into a global representation and standard management protocol used by the Complex Managers and the NMIC. The AOST NMIC and Complex Managers are being implemented using SunNet Manager, a commercial off-the-shelf network management product.

Managed systems comprise two conceptual components: the data processor, which performs the actual processing and presents the agent with a local representation of managed parameters; and the agent, which translates the management information between the local representation and a global representation understood by the Complex Manager. The agent presents the Complex Manager with a view of the processor as a collection of abstract functions and system operation parameters.

The AOST is developing and testing a demonstration version of a standard Management Information Base (MIB) for CCSDS services that can be used by other CCSDS-compliant systems. The MIB includes the CCSDS AOS, Packet Telemetry, and Telecommand (Refs. 19-21) services and protocols, including configuration and performance information, and allows the NMIC, Complex Managers, and managed systems to exchange management information in a common, standard language.

4.1.4 Scheduling/Configuration of the AOST

The CCSDS Recommendations assume data-driven rather than scheduled space data systems. However, all of the C-1 AOST elements require some degree of pre-configuration prior to receiving data. Each time the data parameters change (e.g., a new Spacecraft ID or a different CCSDS service is used), each element must be reconfigured. Typically, reconfiguration is accomplished by loading a pre-defined catalog from disk to memory. If a new configuration is being used, a new catalog must be manually constructed, stored on disk and loaded into memory. This is a time-consuming process that is subject to error.

The loading of catalogs consistent with the expected data stream requires prior knowledge of the data characteristics and is a form of system scheduling. To simplify AOST operations in C-2, reconfigurations will be performed by the automated AOST service management system. The AOST will still be "scheduled," but from a centralized location.

A solution under consideration by the AOST is the use of adaptive frame synchronizers that would automatically determine the frame length of incoming data, the presence/absence of R-S coding, and that would identify the data by examining the Version ID and Spacecraft ID fields in the frame header. The result would be a truly automatic, data driven system.

4.1.5 Data Latency

Some of the elements in the AOST have been developed using a "pipeline" architecture. Incoming data are used to "push" data previously received

through the system. In the AOST environment, this pipelining occurs at the frame level, introducing unpredictable data latency. At the close of any data transmission (such as at loss-of-signal), the last several frames received will lie dormant in the system until they are manually "flushed," flushed after a system time-out, or when frame sync lock is reacquired at acquisition-of-signal. In the third case, data output from system upon reacquisition contains one or more data units that represent "old" data and some that represent "new" data, resulting in unusual and unpredictable latency.

Although unpredictable latency may not be significant to many applications, it is unsuitable for supporting real-time, interactive operations such as "joysticking." Constant latency is more important than low latency in joysticking operations because the operator needs to be able to reliably predict the response time of the system. Data latency that varies unpredictably by orders of magnitude may have serious operational consequences. Operational systems having requirements for constant or low latency must avoid a pipelining architecture.

4.2 Test Suite

An important product of the AOST Program will be the suite of tests that is being developed (Ref. 22). The test suite will be available to organizations wanting to test their existing or new CCSDS-based systems, and will serve as the basis for the conformance and compatibility test suite identified as an AOST Program objective (Ref. 4). The test suite does not currently address performance testing.

The proposed draft test suite is organized in terms of the 22 functions and 8 services defined in the CCSDS AOS Recommendation (Ref. 2). The functions can be divided into data generation functions (transmitting) and corresponding data processing functions (receiving). Specific groupings of these functions comprise procedures that in turn comprise the CCSDS services. Each function may support multiple procedures and services. Examples of functions include fill generation, VCDU commutation, and frame synchronization. Examples of procedures include Channel Access, Packet Transfer, and Bitstream. Examples of services include Virtual Channel Access and Path Packet. A complete listing of the functions, procedures, and services can be found in (Ref. 22).

The test suite provides a framework of standard tests to verify the compliance of any given implementation with the CCSDS Recommendations. Users may select from among the standard tests to accommodate the particular services and function-to-element allocations of their system implementations. Testing

occurs at the function level. After successful testing, the functions can be grouped into procedures and services which are then tested at the procedure or service level. This approach assumes that each service has been implemented using the previously tested functions as "building blocks." The alternative, in which each function is implemented separately for each service, would require independent testing for each function supporting each service.

The CCSDS Recommendations do not define or standardize the parameters or services used by each implementation. Rather, the Recommendations define only the data structures and delimiters for the services. Each flight project is free to choose which services it will support, which virtual channel IDs and application process IDs will be used, and what combinations of services and parameters will be permissible. The standardized test data suite may lead to a test data set generation capability that will permit users to select the functions and services to be tested, the particular data specifications for each implementation, and specific parameters such as Spacecraft IDs, sequence counter starts, etc. The end product of such a data set generation capability would be a test data set consistent with the CCSDS Recommendations that is tailored to the particular implementation being tested.

4.3 Flight-Qualifiable Components

Three CCSDS-based flight-qualifiable components are being developed:

- Reed-Solomon Decoder Chip Set
- Reed-Solomon Encoder
- Packetizer

The R-S Decoder Chip Set comprises four, fully custom VLSI chips using a Euclid algorithm. The Decoder Chip Set was produced by a commercial foundry and cannot be flight-qualified (Ref. 23). It corrects a maximum of 16 symbols at a sustained rate of 80 Mbps. The next-generation flight-qualifiable decoder is being developed as a single chip encoder/decoder. The new chip set will be flight-qualifiable and will perform 1 to 16 symbol error corrections at a sustained data rate of 150 Mbps.

The flight-qualifiable R-S Encoder features a selectable interleave depth (1 to 8) and supports a sustained data rate of 200 Mbps (Ref. 17). This Encoder is currently available for flight project use, and has been baselined by the Tropical Rainfall Measuring Mission and the X-ray Timing Experiment.

The Packetizer is currently being defined. The Packetizer will create CCSDS Packet headers and will support variable or fixed length packets from 64 bytes to 2K bytes. The Packetizer will provide for a 10 MHz input data rate and a 20 MHz output data rate. A preliminary specification is being drafted and will be available in December 1992.

5. SUMMARY

The AOST Program is making significant progress towards its goals of supplying information to ground and flight programs, to industry, and to the CCSDS; developing a conformance and compatibility test suite; and promoting the use of the CCSDS Recommendations for Packet Telemetry and AOS by flight projects. Architecture considerations, including ground rules, a ground/ground data transfer mechanism, service and network management, scheduling, and latency are emerging from the AOST development process and C-1 test program. Additional lessons will result from the continuation of the C-1 test program and the initiation of the C-2 AOST development process. A proposed test suite has been drafted and will be updated and revised as work on the AOST Program continues. Flight-qualifiable components are being developed and prepared for flight-qualification by flight projects.

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